Study of Machining Characteristics in Electrical Discharge Machining (EDM) of Stainless Steel 304

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Abstract **The present work shows an experimental investigation of Electrical Discharge Machining of AISI 304 stainless steel having good wear and abrasion resistance with the tool or electrode of Tungsten carbide. In EDM various techniques are applied to improve material removal rate, surface roughness, and tool wear rate. In this study, a set of experiments, following Taguchi L9 design, are carried out to analyze the effect of three machining parameters viz., discharge current, pulse on time, and applied voltage on process performance parameters such as material removal rate and surface roughness. The signal-to-noise ratios associated with the observed values in the experiments are determined to ascertain the factor that is most affected by the responses of Material Removal Rate and Surface Roughness. Moreover, Analysis of variance (ANOVA) is conducted to find the significant parameters. The present work shows that the pulse on time is the most significant parameter for MRR whereas voltage is the most significant parameter for surface roughness.**

Keywords — **Electrodes, Material removal rate, Surface roughness, Tungsten Carbide Electrode, Taguchi method**

I. INTRODUCTION

Electrical Discharge Machining (EDM) is an advanced machining process primarily used for hard and difficult metals which are difficult to machine with the traditional techniques[1]. Only electrically conducting materials are machined by this process[1]. The EDM process is best suited for making intricate cavities and contours which would be difficult to produce with normal machines like grinders, end-mills or other cutting tools[1]. Metals such as hardened tool-steels, carbides, titanium are easily machined through EDM[1]. EDM is a thermal process which makes use of spark discharges to erode the material from work piece surface. The cavity formed in EDM is a replica of the tool shape used as the erosions occur in the confined area. Since spark discharges occur in EDM, it is also called as "spark machining". The material removal takes place in EDM through a rapid series of electrical discharges. These discharges pass between the electrode and the work piece being machined[4]. The fine chips of material removed from the work piece gets flushed away by the continuous flowing di-electric fluid. The repetitive discharge creates a set of successively deeper craters in the work piece until the final shape is produced [1, 2].

The schematic of basis EDM process is shown in Fig 1.1[4]. In this process the workpiece and tool are submerged into a non-conducting, dielectric fluid which is separated by a small gap for sparking[3]. The dielectric fluid insulates the workpiece from the tool and creates the resistance of electricity flow between the electrodes. The dielectric fluid may be typical hydrocarbon oil or de-ionized water. It also helps in cooling down the tool and work piece, clears the inter-electrode gap and concentrates the spark energy to a small cross sectional area under the electrode.

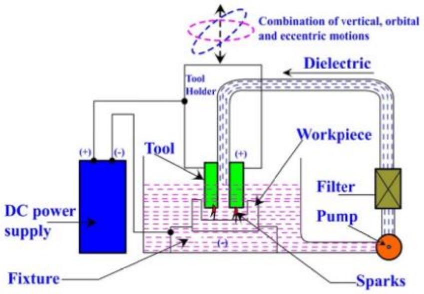

Fig. 1.1 Schematic Diagram of Electric Discharge Machining[11]

Once adequate potential difference is applied by power supply across the small gap of work-piece and tool, high electrical discharge takes place in the form of spark at an interval of 10 of micro second. Then the electron ions present are accelerated towards the positive ions, a discharge passage that turn out to be conductive. It is only at a given instant of time when the suitable voltage is built up across the tool and work piece the accelerated electron ions may ultimately collide with the dielectric fluid molecules causing creation of a passage of plasma. An instant fall of the electrical resistance of the plasma passage permits that current density attains very large amounts, creating a rise of ionization between molecules and powerful magnetic field results of a very high temperature on the electrodes in the range of (10000 - 12000ºC). This high temperature spark causes sufficiently compressive force developed between work piece and tool as an outcome that more or less metallic particles are liquefied and eroded[10]. Material removal takes place because of on the spot vaporization of the metallic particle as well as owed to melting process. The melted particle is not withdrawn altogether, however just partly[10]. By means of the potential difference is drawn the plasma passage is no longer continued[1o]. As the plasma passage breakdown, it produces pressure force or shock waves, which clears the molten material by flushing method making a depression of removing material all over the place of the spark.[1, 2].

II. PROCEDURES

A. Objective

The main objective of the study is to analyze the effect of EDM, the basic theory of which is explained in previous section, machining parameters namely discharge current, pulse on time and voltage on the output performance such as material removal rate, surface roughness during machining of AISI 304 stainless steel work piece by using Tungsten Carbide tool material.

B. Formula of MRR Calculation

MRR(Material Removal Rate) is calculated by the following formula :

$$\mathrm{MRR} = \frac{W_{bm} - W_{am}}{t \times \rho} \tag{1}$$

where,

w_{bm} = Weight of workpiece before machining.

w_{am} = Weight of workpiece after machining

t = Machining period = 10 min.

ρ = Density of AISI 304 stainless steel work piece = 8000 kg/m^3

Measurement of Surface Roughness

Surface Roughness is the size of the surface texture. It is expressed in µm and denoted by Ra. If the value comes higher than a reference value the surface is rough and if lower, the surface is smooth. The surface roughness values are measured by means of portable profilometer.

C. Experiment Design :

In the present analysis, Taguchi Design procedure has been followed for carrying out the experiments. Dr. Genichi Taguchi's approach or DOE (Design of Experiment) is highly effective wherever and whenever it is suspected that the performance of a part or process is controlled by more than one factor[7]. A Taguchi design is a designed experiment that lets one choose a product or process that functions more consistently in the operating environment[7]. Taguchi designs recognize that not all factors that cause variability can be controlled. These uncontrollable factors are called noise factors. Taguchi designs try to identify controllable factors (control factors) that minimize the effect of the noise factors[7]. Following Taguchi design methodology of experimentation, optimal control factor settings are determined that make the process or product robust, or resistant to variation from the noise factors. A process designed with this goal will produce more consistent output. A product designed with this goal will deliver more consistent performance regardless of the environment in which it is used. [3, 4]

A number of ordinary orthogonal arrays have been created in Taguchi procedure to determine experimental design. Each of these arrays can be used to design experiments to suit numerous experimental situations. A number of orthogonal arrays, such as L_4, L_8, L_9, L_{12}, L_{16}, L_{18}, and L27 and so on, can be created for two or three level factors. To measure the performance of the response variable (here, MRR), Taguchi uses signal to noise (S/N) ratio approach[11]. Again, analysis of variance(ANOVA) is used to find the significant process parameter[12]. With the help of ANOVA and S/N ratio analysis, the optimal process condition is predicted. MINITAB software may be used for necessary analyses to obtain the desired results.

Following Taguchi's methodology, the present experiments are conducted by considering discharge current (Ip), pulse duration (Ton) and voltage (V) as control parameters each at three level and the experimentations are varied to complete 9 altered trial.

The levels of experiment parameters are shown in Table 1.1.

Table 11

Machining Parameter	**Symbol**	**Unit**	**Levels**		
			Level 1	**Level 2**	**Level 3**
Discharge Current	Ip	A	5	7	9
Voltage	V	V	45	55	65
Pulse on time	Ton	µs	50	150	200

III. OBSERVATION TABLE

The experiments are for nine numbers of different combinations considering the three control parameters i.e., discharge current (Ip), pulse duration (Ton) and voltage (V) at three different levels. The weight of workpiece before machining and after machining for each run is calculated with the help of weighing machine and MRR is calculated by formulae mentioned above. Each experiment is conducted for 10 minute i.e., for each experiment machining time is 10 minute. After each experiment surface roughness(SR) is measured.

The experimental data and corresponding results are presented in the following Tables.

Table 1.2

Run S.No.	**Ip (A)**	**Voltage (V)**	**Ton (µs)**	**Wt. of work piece (in gm.)**	
				w_{bm}	w_{am}
1	5	45	50	150.592	150.356
2	5	55	150	150.356	150.030
3	5	65	200	150.030	149.758
4	7	55	50	149.758	149.371
5	7	65	150	149.371	148.886
6	7	45	200	148.886	148.358
7	9	65	50	148.358	147.883
8	9	45	150	147.883	147.145
9	9	55	200	147.145	146.464

Table 1.3

Run no.	**Ip (A)**	**Voltage (V)**	**Ton (µs)**	**MRR (mm^3/min)**	**SR (µm)**
1	5	45	50	2.9500	5.9333
2	5	55	150	4.0750	7.1333
3	5	65	200	3.4000	8.4000
4	7	55	50	4.8375	5.2667
5	7	65	150	6.0625	7.8000
6	7	45	200	6.6000	7.1333
7	9	65	50	5.9375	8.4000
8	9	45	150	9.2250	4.2000
9	9	55	200	8.5125	4.6667

IV. RESULT AND DISCUSSION

A. *Influence on MRR*

Taguchi method is used to analysis the result of machining parameter for "larger is better" criteria[15]. The S/N ratios for MRR are calculated by using the equation (2)

$$\text{LB: } \eta = -10 \log \left[\frac{1}{n} \Sigma_{i=1}^{n} yi^{-2}\right] \qquad (2)$$

Where, η denotes the S/N ratios calculated from observed values

yi represents the experimentally observed value of ith experiment

n=1 is repeated number of each experiment in L-9 Orthogonal Array

MINITAB 17 software is used for further analysis. figure 1.2, figure 1.3 and figure 1.4 indicates that MRR at 9A discharge current , 45v voltage and 150 µs pulse on time respectively gives the best result on input parameter.

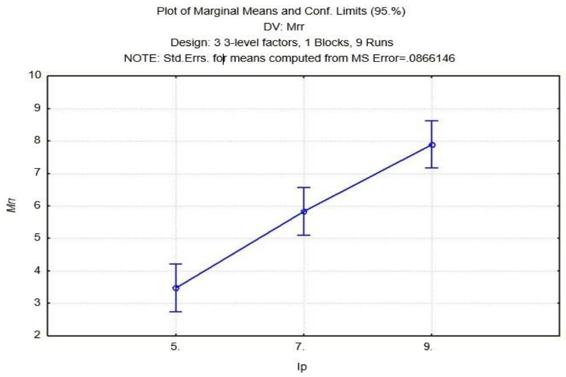

Fig 1.2 Mean plot of MRR (mm^3/min) verses Ip (A)

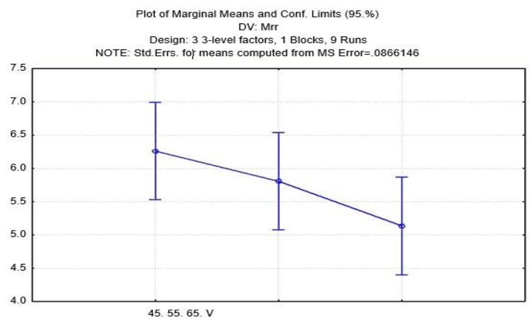

Fig 1.3 - Mean plot of MRR (mm^3/min) versus Voltage (V)

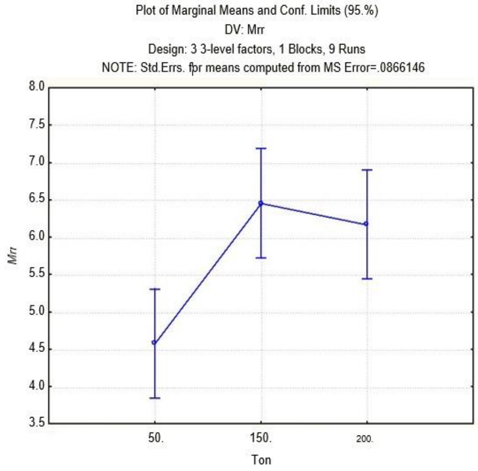

Fig 1.4 –Mean plot of MRR (mm^3/min) versus Ton (µs)

Analysis of variance, ANOVA studied from the effect of factor on MRR is indicated in Table 1.4 which indicates that the discharge current is most significant factor while machining of AISI 304 Stainless steel with tungsten carbide tool after that pulse on time is also an important parameter and voltage is not significant factor during machining. Figure 1.5 represent that the main effect of S/N ratio on MRR by the factor. For this case "higher is better "is chosen.

Table 1.4

Effect	**Analysis of Variance (MRR)Mean = 14.5931 Sigma = 3.40187**				
	SS	**Df**	**MS**	**F**	**P**
1 Ip	76.42654	2	38.21327	1857.607	0.000538
2 Ton	14.00673	2	7.00337	340.445	0.002929
3 V	2.10735	2	1.05367	51.221	0.019149
Residual error	0.04114	2	.02057		

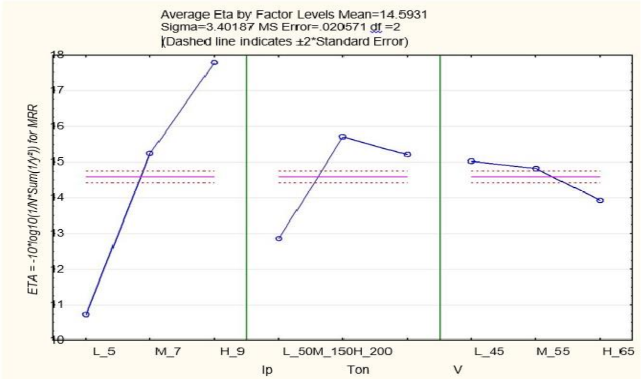

Fig 1.5 – S/N ratio plot for MRR

B. Influence on SR

Taguchi method is used to analysis the result of response of machining parameter for “smaller is better”[15]. The S/N ratio for Surface roughness are calculated by using the equation (2)

$$\text{SB: } \eta = -10\log\left[\frac{1}{n}\Sigma_{i=1}^{n} yi^2\right]$$

Equation (2)

Where, η denotes the S/N ratios calculated from observed values

yi represents the experimentally observed value of ith experiment

n= 1 is repeated number of each experiment in L-9 Orthogonal Array

According to Figure 1.6, Figure 1.7 and Figure 1.8 which shows that the Surface Roughness at 7A current, voltage of 55V and 50 µs of pulse on time respectively gives the better results for surface roughness is obtained.

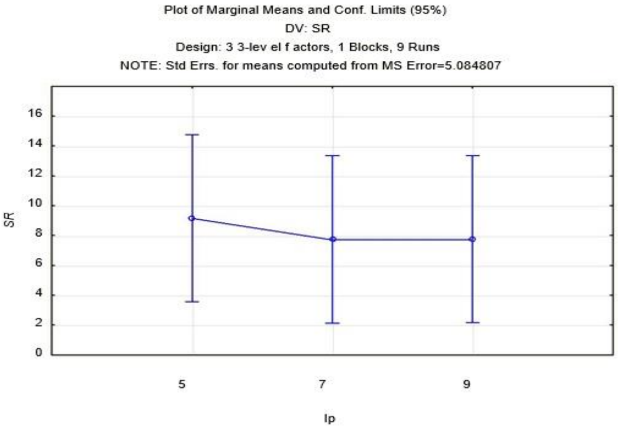

Fig 1.6- Mean plot of SR (µm) versus Ip (A)

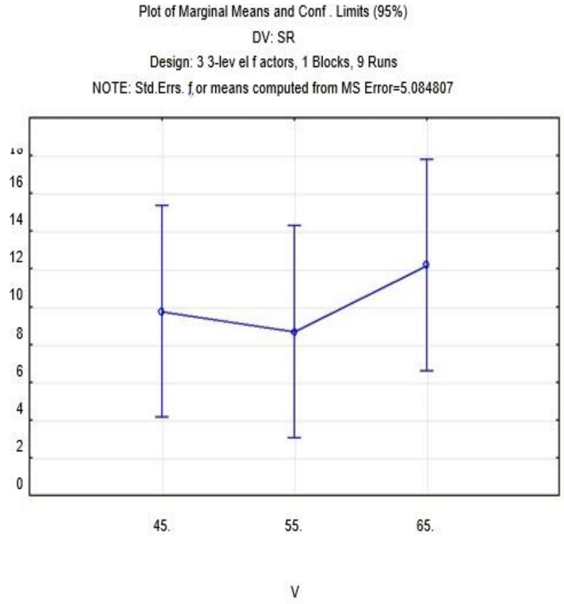

Fig 1.7 - Mean plot of SR (µm) versus Voltage (V)

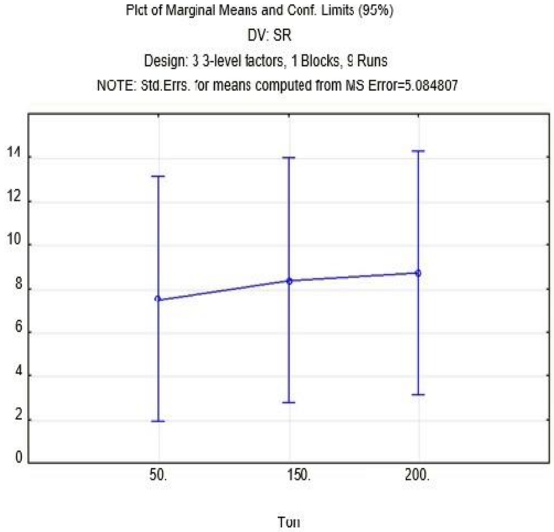

Fig 1.8 - Mean plot of SR (µm) versus Ton (µs).

To know the statistical validity of the developed experimental setup on ANOVA analysis (Table 1.5) is performed, percentage contribution of voltage is about 65.64% states the impact of voltage on surface roughness of the work-piece in EDM process. The parameters such as discharge current (Ip) and pulse on time (Ton) has very less impact on surface quality of the work-piece. The analysis states that the effectiveness of the voltage on the EDM process

Table 1.5

Effect	Analysis of Variance (SR)				
	SS	Df	MS	F	% Contibution
1 Ip	14.5668	2	7.28341	0.407676	0.19139
2 Ton	11.5843	2	5.79219	0.324208	0.152204
3 V	49.9595	2	24.97975	1.398199	0.656406
Residual error	35.7313	2	17.86566		

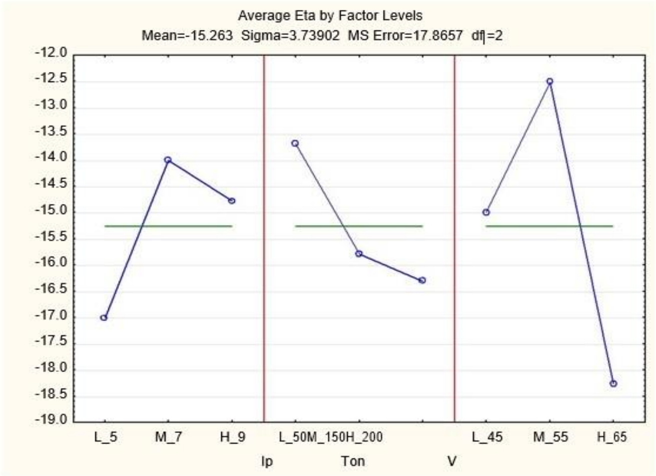

Fig 1.9- S/N ratio plot of Surface Roughness

V. CONCLUSION

From the results of MRR we conclude that the discharge current is most significant or influencing factor, then pulse on time and voltage has the least influence.

1. From the results of MRR we conclude that the discharge current is most significant or influencing factor then pulse on time and at last is voltage on the given input.
2. MRR increases linearly with some extent of current and decreases slightly with pulse on time.
3. In case of surface roughness the voltage is the effective parameter after that current and voltage are less effective on machined work piece.

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